USE OF HYBRID PLUME/GRID MODELING AND THE ST. LOUIS SUPER SITE DATA TO MODEL $PM_{2.5}$ CONCENTRATIONS IN THE ST. LOUIS AREA

Ralph Morris*, Bonyoung Koo, Jeremiah Johnson and Greg Yarwood
ENVIRON International Corporation, Novato, CA, USA

Jay Turner and Jennifer Garlock
Washington University, St. Louis, MO, USA

Calvin Ku, Wendy Vit, Adel Alsharafi and Jeff Bennett
Missouri Department of Natural Resources, Jefferson City, MO, USA

1. INTRODUCTION

The St. Louis region was designated as nonattainment for both the 8-hour ozone and $PM_{2.5}$ National Ambient Air Quality Standards (NAAQSs) by the U.S. Environmental Protection Agency (EPA). The Illinois Environmental Protection Agency (IEPA) and Missouri Department of Natural Resources (MDNR) are developing common 8-hour ozone and $PM_{2.5}$ emission control plans for the St. Louis region with a 2010 attainment date. ENVIRON International Corporation was retained by the MDNR to assist in the 8-hour ozone and $PM_{2.5}$ modeling for the St. Louis State Implementation Plan(SIP). During Phase I of the work effort, that was mainly performed in 2005, ENVIRON assisted in the development 36/12/4 km CMAQ and CAMx ozone modeling databases for three episodes from 2002. Under Phase II in 2006, ENVIRON assisted in the completion of the 8-hour ozone modeling for the three 2002 episodes, performed the final 2009 8-hour ozone attainment demonstration modeling and wrote the air quality Technical Support Document (TSD) that was included with the St. Louis 8-hour ozone SIP submitted in June 2007. Phase III of the work (2007) is focusing on the development of an annual 2002 36/12 km $PM_{2.5}$ regional modeling database to be used for the $PM_{2.5}$ SIP due April 2008.

2. $PM_{2.5}$ NONATTAINMENT PROBLEM IN ST. LOUIS

The St. Louis region has been designated nonattainment for $PM_{2.5}$ based on measured violations of the annual $PM_{2.5}$ NAAQS. The annual $PM_{2.5}$ NAAQS is based on the $PM_{2.5}$ Design Value that is the three year average of annual $PM_{2.5}$ concentrations with a threshold of 15.0 µg/m^3. Figure 1 displays the 2003-2005 $PM_{2.5}$ Design Values for the St. Louis area. There are two monitoring sites that violate the annual $PM_{2.5}$ NAAQS: Granite City and East St. Louis that have 2003-2005 PM Design Values of 17.0 and 15.5 µg/m^3, respectively. Both of these monitors are in the Illinois portion of the St. Louis nonattainment area.

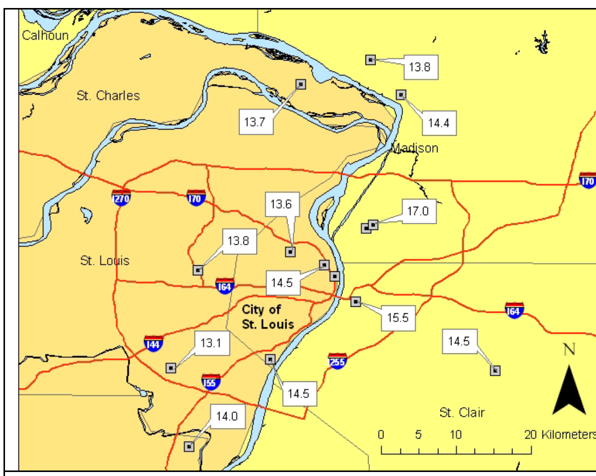

Figure 1. Annual $PM_{2.5}$ Design Values in the St. Louis region based on 2003-20005 monitoring data (Source: Turner and Garlock, 2007).

3. REGIONAL $PM_{2.5}$ MODELING FOR ST. LOUIS

ENVIRON and MDNR are developing a regional 36/12 km $PM_{2.5}$ modeling database for the 2002 annual period and the St. Louis region. Figure 2 displays the 36/12 km grid structure used in the St. Louis regional-scale modeling; the larger 12 km grid is being used. The SMOKE emissions

**Corresponding author:* Ralph Morris, ENVIRON International Corporation, 101 Rowland Way, Novato, CA USA 94945. e-mail: rmorris@environcorp.com. (415) 899-0708; FAX: (415) 899-0707

model is being used to generate emissions for the 36/12 km grid and a 2002 base case. The CMAQ and CAMx models were used to model 2002 and 2009 using the Base D emissions. The Base 4 emissions were updated to Base G and CMAQ was rerun for the 2002 and 2009 base case Base G emission scenarios. The CMAQ and CAMx Base D and CMAQ Base G 2002 and 2009 modeling results were used to project $PM_{2.5}$ Design Values for comparisons with the 15.0 $\mu g/m^3$ annual $PM_{2.5}$ standard. Two sites, Granite City and East St. Louis, are projected to still violate the annual $PM_{2.5}$ NAAQS in 2009. The 2009 $PM_{2.5}$ Design Value at Granite City is projected to be 1 to 1½ $\mu g/m^3$ higher than the annual standard. Because it will be difficult to implement additional controls in time to achieve attainment by 2009, the MDNR is pursuing modeling of the 2012 period.

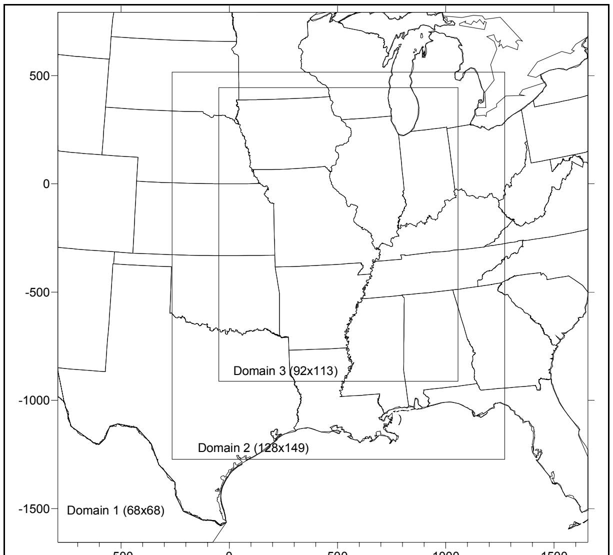

Figure 2. 36/12 km domain being used for the St. Louis 2002 annual $PM_{2.5}$ regional-scale modeling.

4. DATA ANALYSIS USING ST. LOUIS PM SUPER SITE DATA

The St. Louis Super Site has collected detailed PM measurements in the St. Louis area for several years, including 2002, that has allowed the use of advanced data analysis techniques to better understand the $PM_{2.5}$ problem in St. Louis. Figure 2 shows the results of $PM_{2.5}$ source apportionment modeling using the Positive Matrix Factor (PMF) receptor model and the St. Louis Super Site East St. Louis monitoring data. PMF decomposes the measured $PM_{2.5}$ into "factors" that are then associated with "source types". The largest factors identified by PMF are secondary sulfate, secondary nitrate, organic carbon plus secondary sulfate, urban carbon (mobile) and biomass burning. These factors are primarily regional in nature. Steel production is also identified as a significant source of the East St. Louis $PM_{2.5}$ contributing 1.28 $\mu g/m^3$ of the annual value (7.2%) with smaller contributions due to Zinc and Lead smelting (approximately 0.3 $\mu g/m^3$ each). These factors are more related to local sources.

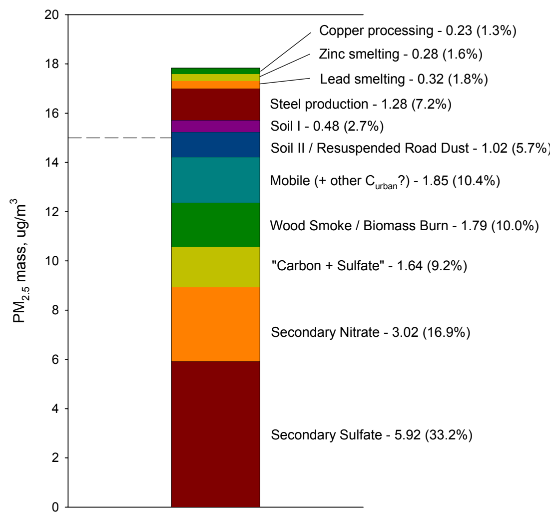

Figure 3. $PM_{2.5}$ source apportionment at East St. Louis (Source: Turner and Garlock, 2007).

Figure 4 displays another PMF analysis that combines the PMF analysis for the Industrial Point Source #1 factor with wind data at East St. Louis and indicates that the largest $PM_{2.5}$ contributions associated with this factor at the East St. Louis monitor are coming from the north, which is the direction of Granite City. Turner and Garlock (2007) also performed an analysis of the local versus regional contributions of $PM_{2.5}$ at the Granite City monitor which is summarized in Figure 5. Also shown in Figure 5 is the outline of the U.S. Steel Granite City Works (GCW) facility, with the steel production in the western and coke ovens in the eastern portion of the facility.

The data analysis using the advanced St. Louis Super Site PM data clearly shows that the $PM_{2.5}$ problem in St. Louis is a combination of regional (Figure 3) and local (Figures 4 and 5) sources. Consequently a hybrid modeling approach is needed that accounts for PM contributions from the local-scale using a plume model and at the regional scale using a full chemistry photochemical grid model.

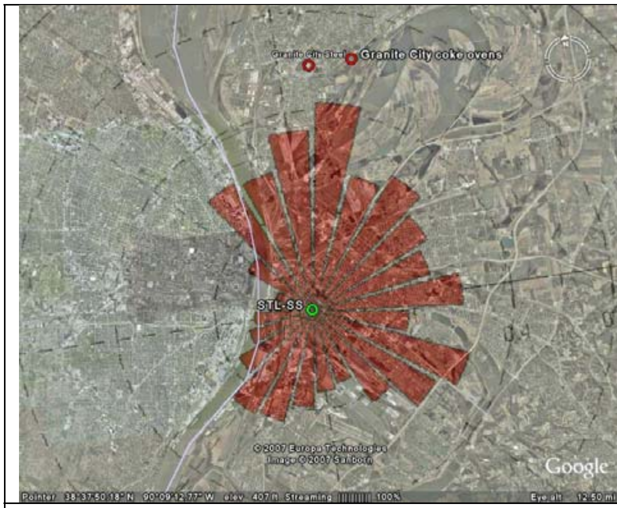

Figure 4. Combination of PMF Industrial Point Source #1 factor with wind data (Source: Turner and Garlock, 2007).

Figure 5. Wind analysis showing predominate wind directions when $PM_{2.5}$ concentrations at the Granite City monitor (location B) exceed the regional background $PM_{2.5}$ levels and outline of U.S. Steel Granite City Works facility (Source: Turner and Garlock, 2007).

5. HYBRID PLUME/GRID MODELNG APPROACH

5.1 Alternative Plume/Grid Hybrid Modeling Approaches

The regional 2002 36/12 km CMAQ/CAMx database can not address the local-scale contributions to $PM_{2.5}$ concentrations at Granite City. Thus, four approaches for treating local-scale impacts within the overall context of the 2002 36/12 km CMAQ/CAMx modeling were considered:

1. Hybrid Modeling using Regional Photochemical Grid Model and Local-Scale Gaussian Plume Model: In this approach a regional model (e.g., CMAQ and CAMx) would be used to represent the regional and urban scale contribution and a plume model, such as AERMOD or CALPUFF, that would be used to represent the contribution of local sources.

2. Use CAMx with the Subgrid-Scale Plume-in-Grid (PiG) Model for Local Sources: CAMx includes a subgrid-scale Plume-in-Grid (PiG) module to model the near-source transport, dispersion and chemistry of point sources. When the PiG plume size is commensurate with the grid cell size or chemical maturity is reached in the plume, the mass in the plume is released to the grid model for further tracking. The CAMx PiG module has been updated to work with a receptor sampling grid to obtain subgrid-scale concentrations at user-specified receptor locations. CMAQ also includes a Plume-in-Grid (PinG) module but it is designed for large power plant plumes not local contributions of point sources.

3. Use CMAQ or CAMx with Finer Grids (e.g., 1 km or smaller): Finer grid spacing using either CMAQ or CAMx models would also better represent the impacts of local sources. However, even a 1 km grid would not to be sufficient to represent the separation between the GCW facility and the Granite City monitor.

4. Use CAMx with Both Finer Grids and PiG: This approach combined the approaches listed in 2 and 3 above.

Because the CMAQ/CAMx regional grid models are designed to be accurate and the AERMOD/CALPUFF models are designed to be conservative, a hybrid plume/grid modeling approach mixing these two types of models is problematic. EPA guidance (EPA, 2007) suggests splitting the $PM_{2.5}$ Design Value into a regional and local component and then using the grid and plume models to project the separate component. However, how the Design Value is split is somewhat arbitrary. Thus, the IEPA and MDNR decided to explore the fourth approach to use an integrated hybrid grid/plume model to account for local as well as regional primary and secondary PM impacts within a single integrated unified modeling system.

5.2 Integrated Hybrid Plume/Grid Modeling approach

The St. Louis integrated hybrid plume/grid model would be based on the Comprehensive Air Quality Model with extensions (CAMx; ENVIRON, 2006) that incorporates a subgrid-scale Plume-in-Grid (PiG) model. The CAMx PiG has been recently updated to include second order closure (SOC) dispersion coefficients and the ability to use a receptor file to allow the subgrid-scale sampling of the PiG plumes. CAMx would be set up on a 12/4/1 km nested-grid configuration, like that shown in Figure 6. Boundary conditions (BCs) for the outer edges of the 12 km domain in Figure 6 would be based on a regional CMAQ or CAMx simulation on the St. Louis 36/12 km grid (see Figure 2). The feasibility of using a fourth grid nest finer than 1 km will be investigated (e.g., 333 m), however modifications to the horizontal diffusion coefficient algorithms would likely be needed (e.g., use of the SOC dispersion values). The 12/4/1 km and possibly 333 m grids would be run using fully interactive two-way grid nesting.

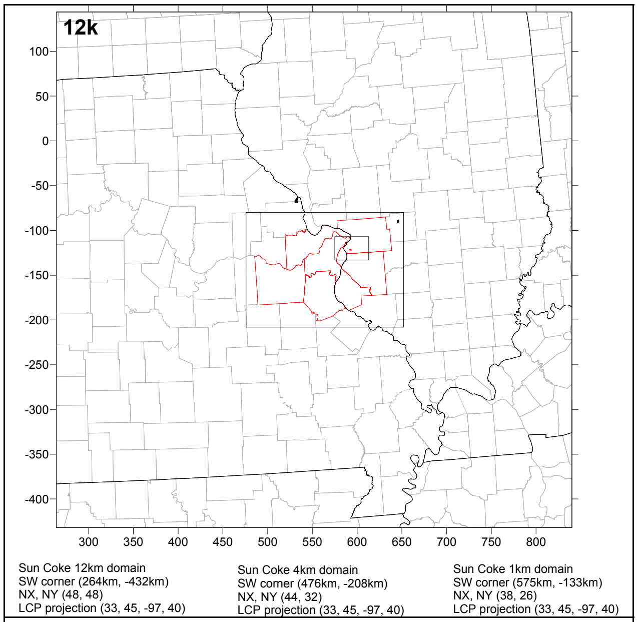

Figure 6. Potential 12/4/1 km nested-grid modeling domain for St. Louis $PM_{2.5}$ modeling.

6. CONCLUSIONS

Exceedances of the $PM_{2.5}$ NAAQS in St. Louis are due to the combination of regional and local sources. Thus, to demonstrate attainment of the $PM_{2.5}$ standard will require addressing the contributions and effects of controls at several scales. The unified multi-scale CAMx photochemical grid/plume model will be used to address this issue. It includes a full-chemistry Plume-in-Grid (PiG) plume model with second order closure dispersion and receptor sampling capabilities.

7. REFERENCES

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